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OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 12/5/79

Project Title: The Early Detection of Arterial Disease

Project No: E-23-502 *Go*

Project Director: Dr. Raymond P. Vito

Sponsor: Georgia Engineering Foundation, Inc.

Agreement Period: From 12/1/79 Until 9/1/80

Type Agreement: Letter dated 11/10/79 for GEF Project No. 79-40

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\$2,500 TOTAL

Reports Required: Final Report

Sponsor Contact Person (s):

Technical Matters

Contractual Matters
(thru OCA)

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Defense Priority Rating: N/A

Assigned to: Engineering Science & Mechanics (School/Laboratory)

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GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT TERMINATION

Date: 4-27-81

Project Title: The Early Detection of Arterial Disease

Project No: E-23-502

Project Director: Dr. R. P. Vito

Sponsor: Ga. Engineering Foundation

Effective Termination Date: 9/1/80

Clearance of Accounting Charges: 9/1/80

Grant/Contract Closeout Actions Remaining:

NONE

- ☐ Final Invoice and Closing Documents
- ☐ Final Fiscal Report
- ☐ Final Report of Inventions
- ☐ Govt. Property Inventory & Related Certificate
- ☐ Classified Material Certificate
- ☐ Other _____

Assigned to: ESM (School/Laboratory) ~~XXXXXXXX~~

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THE MECHANICAL PROPERTIES OF ARTERIES

AS A FUNCTION OF LOCATION

ALONG THE AORTIC TREE

A REPORT^{*} TO THE
GEORGIA ENGINEERING FOUNDATION

by

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SEPTEMBER 3, 1980

* MATERIAL IN THIS REPORT IS TAKEN FROM THE M. S. THESIS OF ROBERT McCALL

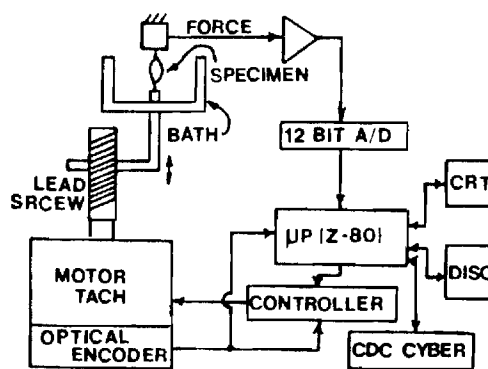
INTRODUCTION

Heart and arterial disease is a leading cause of death and disability in the United States. Studies of arterial mechanics are motivated by interest in clarifying the role of wall stress in the genesis of arterial disease (Fry 1973) or by the compositional changes of arteries associated with the disease. The later have a potential application to the non-invasive detection of the disease as reviewed by Fronek (1973).

It is known that the mechanical properties of arteries are determined by the connective tissues collagen and elastin. This paper examines the relationship between arterial mechanics and connective tissue composition. In this initial study, the variation in response of the canine artery at various locations to uniaxial loading and unloading is compared to previously reported data on tissue composition for each location.

Instrumentation

Microprocessor based instrumentation developed specifically for tissue analysis was used for the studies. The system is shown in block form below.



The system is similar to the described for biaxial measurements (Vito 1979), with the exception that displacement is measured by encoder impulses from the motor. Data is taken using a programmable interrupt timer and an A/D converter

interfaced to the computer. The measured dimensions of the specimen, rate of deformation, and peak Eulerian stress are input to the microprocessor before each experiment. This enables the experimenter to completely define each experiment before it begins. After the experiment, data is analyzed on the Georgia Tech mainframe.

Experiment

Specimens of aorta were taken from five healthy dogs of varying age, sex, and weight, sacrificed by overdoses of phenylbarbital. The aortic tree was removed intact and stored in saline at 5°C.

Each specimen was prepared by cutting a piece of aorta in a rectangular strip approximately 3.0cm by 0.7cm wide. The specimen was cataloged by the location on the aorta from which it was taken and orientation (longitudinal or circumferential). The original dimensions were measured: length (L_0), width (W_0), and thickness (t_0). The specimen was mounted in a saline bath maintained at 37°C. Each specimen was subjected to a uniform protocol of constant strain rate load/unload cycles.

In such tests, the specimen length at zero force changes approaching a limit (L_{pc}) after 5/10 load/unload cycles (Fung 1973). This length served as the basis for analysis. Since the deformation is large, the Eulerian stress $T = F/A$, where A is the area of the deformed cross section, is relevant. Since tissue, being mostly water, is relatively incompressible, $A_0 L_0 = AL$ where L is the deformed length. The Eulerian stress is then $T = FL/A_0 L_0$. Since the mechanical response of tissue is highly dependent on strain history (Fung 1973), the peak value of T and strain rate were controlled. By defining the endpoints on the basis of stress, variation in results may better reflect the structural variations and differences in anatomical orientation among the specimens.

Analysis

Individual load/unload cycles were analyzed using the theory of large elastic deformation (Vito 1979). The data was found to fit quite well a two parameter model $W(I_1, I_2) = \alpha \exp[\beta(I_1 - 3)]$, where I_1 and I_2 are the strain invariants while α and β are the material constants, unique to each experiment, determined by a least squared fit of the data.

Results and Discussion

A preliminary analysis was performed on data on longitudinal specimens for a peak Eulerian stress of 1×10^6 Dynes/cm² and strain rate of 0.005/sec. Table 1 shows the material constants for each location and the strain energy density representing the "hysteresis loop" of the load/unload cycle. The strain energy density is a measure of the energy absorbed per cycle of the tissue.

Figure 1 shows the plot of a typical data file. Figures 2 to 5 are graphical representations of the results showing the mechanical properties α and β at the different locations.

Although based on limited data which exhibit the significant deviations characteristic of biological tissues, there is a marked drop in the parameter α and a corresponding rise in β from the upper section to the lower section of the aorta.

Results of previous experiments on tissue composition(Harkness 1957) are shown in Figure 6. There is seen a marked drop in $E/(E + C)$ (where E is elastin content and C is collagen content) from the upper section to lower section of the aorta. Since our study uses a "fixed effects" model at only five different anatomical locations, a direct comparison of the content to the mechanical properties at the various locations is speculation. Other factors, such as orientation of microstructure are also important.

It is interesting to note that there is a visual correlation of the parameter α and a corresponding inverse correlation of β to the composition ratio $E/(E + C)$ at the different locations.

Conclusion

Uniaxial tests were conducted at various anatomical locations of canine aorta. Preliminary results indicate significant differences in material properties at the various locations. A visual comparison made between earlier composition studies and the mechanical response shows a trend that, if verified by more data and more anatomical locations, could provide meaningful understanding of the mechanical properties of the arterial connective tissue.

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1. Fronek, K., Johansen, K. H., Dilley, R. B., and Bernstein, E. F., Non-invasive physiologic tests in the diagnosis of and characterization of peripheral arterial occlusive disease. Am. J. Surg. 126: 205-13 (1973).
2. Fry, D. L., Response of the arterial wall to certain physical factors. In CIBA Foundation Symposium 12 (new series) Atherogenesis: Initiating Factors 93-120, Assoc. Scientific Pub. (1973).
3. Fung, Y. C., Biorheology of soft tissues. Biorheology 10:139-155 (1973).
4. Vito, R. P., The mechanical properties of soft tissues I: A mechanical system for bi-axial testing. Accepted for publication in J. Biomech. (1979).
5. Vito, R. P., The mechanical properties of soft tissues. II: The elastic response of arterial segments. Accepted for publication in J. Biomech. (1979).
6. Harkness, M. L., Harkness, R. D., McDonald, D. A., The collagen and elastin content of arterial wall in the dog. Proc. Royal Soc. 146: 541-551 (1957).

TABLE 1. THE MATERIAL PROPERTIES OF CANINE AORTA AT DIFFERENT
ANATOMICAL LOCATIONS. PEAK EULERIAN STRESS = 1×10^6 DYNES/CM²
LONGITUDINAL SPECIMENS ONLY

LOCATION OF AORTA	NUMBER OF EXPERIMENTS	"LOOP" STRAIN ENERGY DENSITY (DYNES/CM ²)	α (LOADING) (10^4 DYNES/CM ²)	β (LOADING)	α (UNLOADING) (10^4 DYNES/CM ²)	β (UNLOADING)
UPPER THORACIC	7	11200 \pm 1200	19.9 \pm 2.6	0.830 \pm 0.116	14.2 \pm 2.0	1.033 \pm 0.173
MIDDLE THORACIC	6	12500 \pm 2,300	19.4 \pm 2.3	1.023 \pm 0.133	13.5 \pm 1.4	1.253 \pm 0.156
LOWER THORACIC	6	6500 \pm 300	13.6 \pm 3.4	1.056 \pm 0.168	11.3 \pm 3.2	1.124 \pm 0.170
UPPER ABDOMINAC	4	7200 \pm 1,800	6.2 \pm 1.8	1.956 \pm 0.520	4.8 \pm 1.2	2.131 \pm 0.538
LOWER ABDOMINAC	4	5500 \pm 700	3.5 \pm 0.7	2.372 \pm 0.281	3.0 \pm 0.7	2.483 \pm 0.286

Figure 1. Stress strain curve for dog aorta. λ is the ratio L/L_{PL} where L = Specimen length and L_{PL} = length at the beginning of cycle.

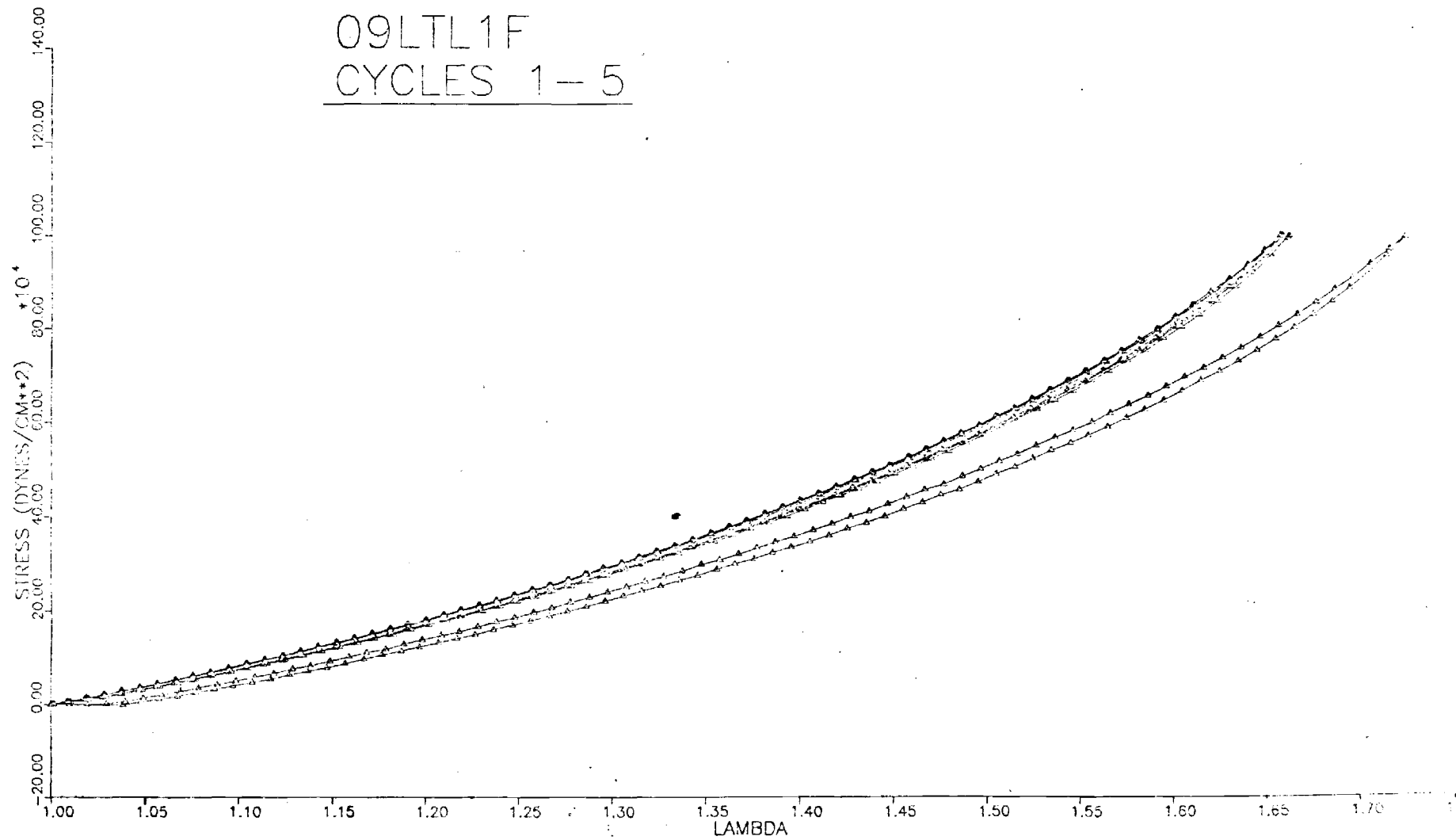


FIGURE 4

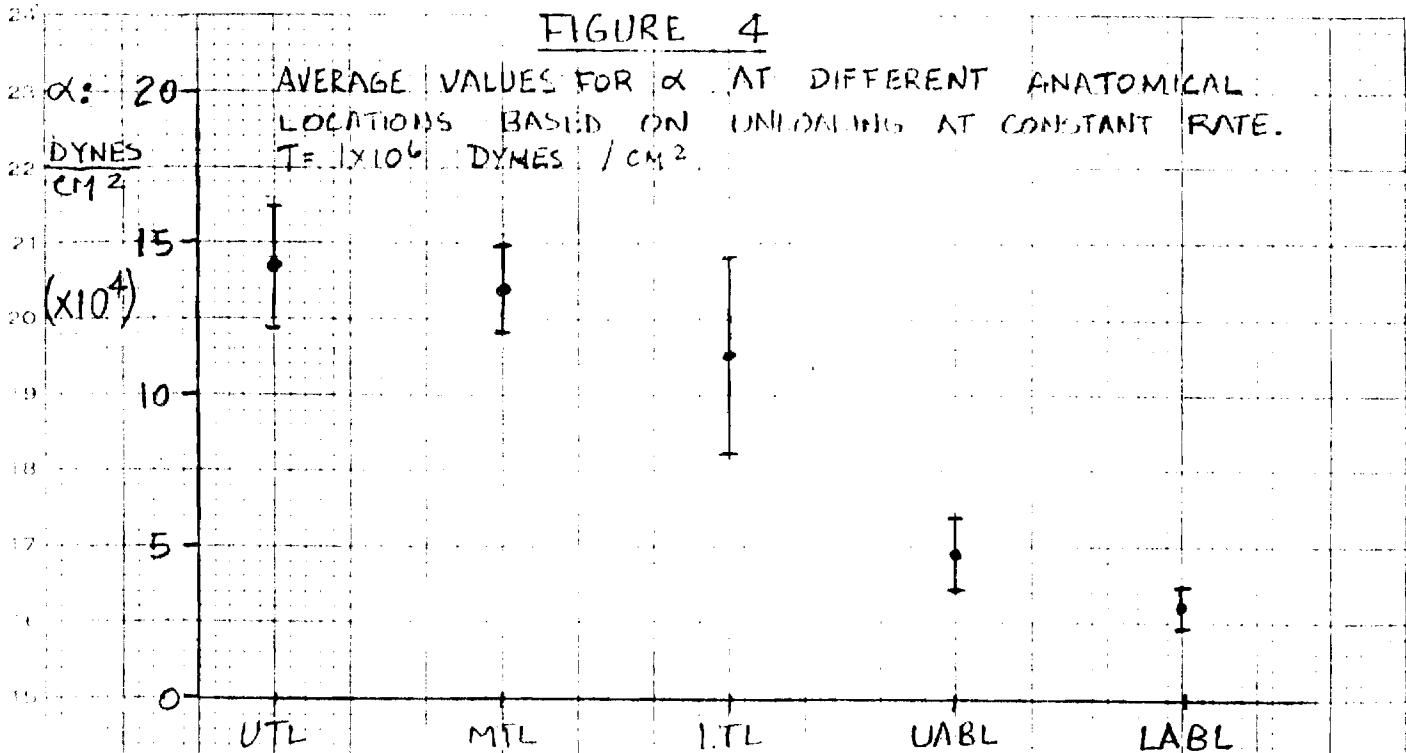


FIGURE 5

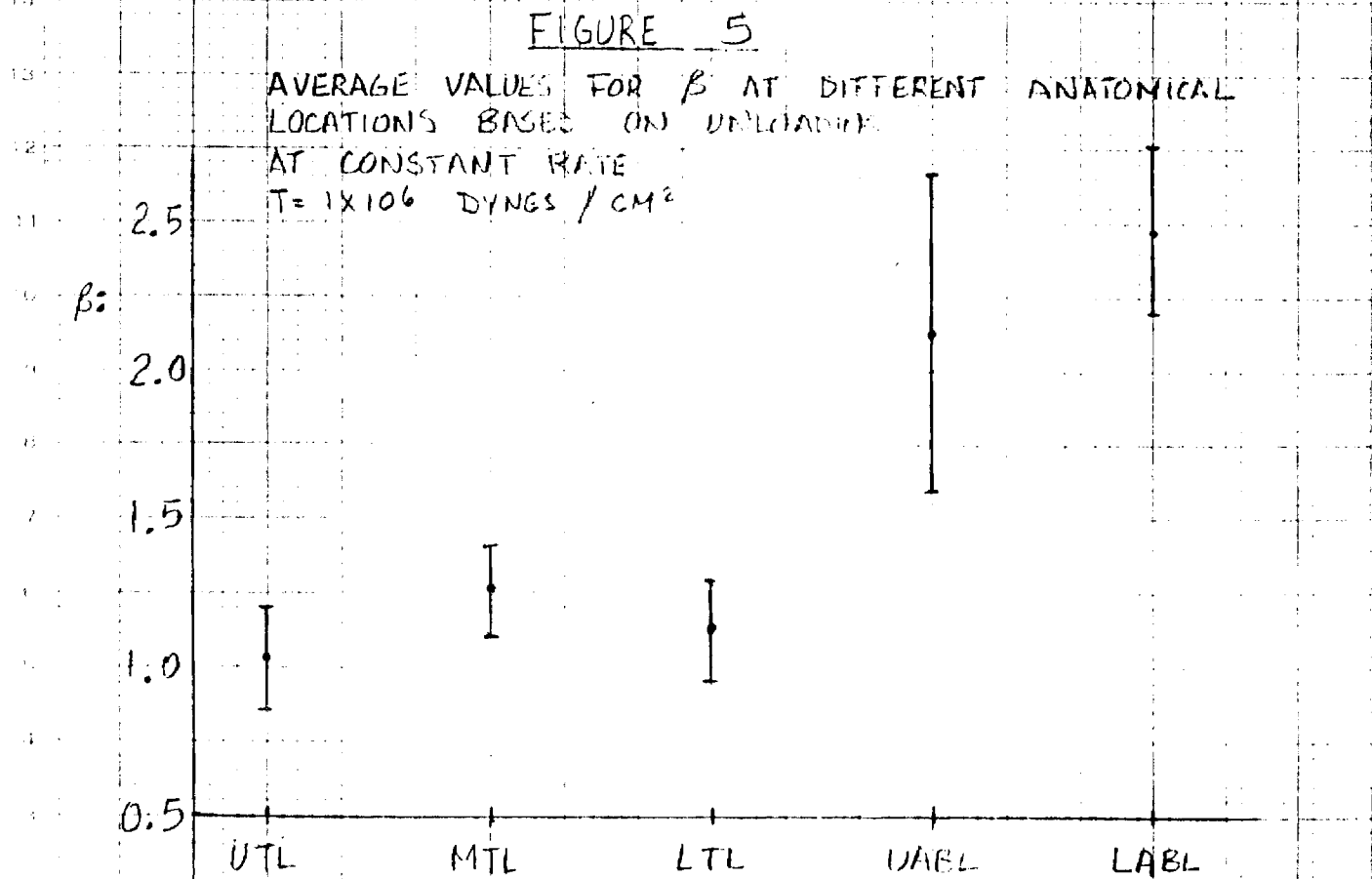


FIGURE 6

RATIO OF ELASTIN TO COLLAGEN + ELASTIN IN DIFFERENT SITES OF CANINE AORTA. REDRAWN FROM HARKNESS, ET AL.

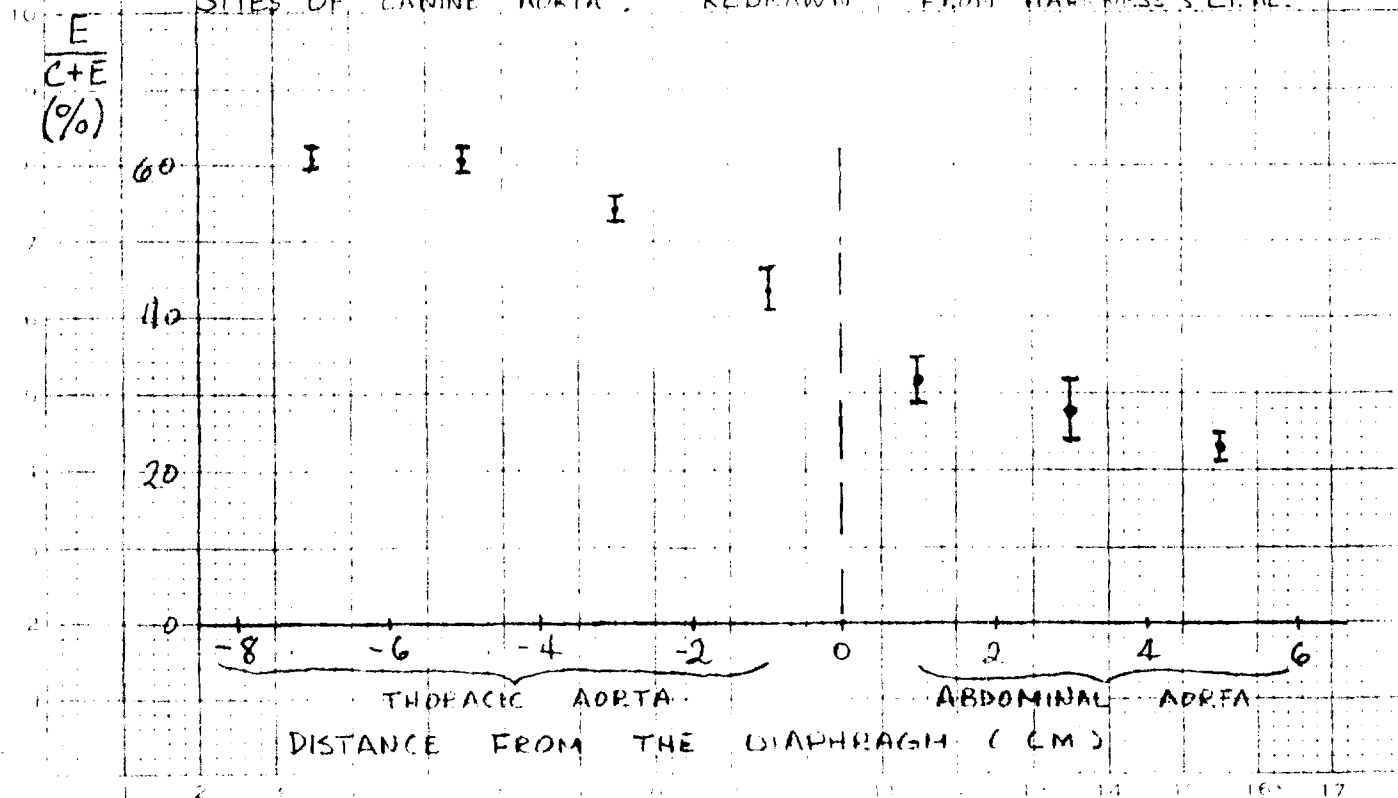


FIGURE 2

AVERAGE VALUES FOR α AT DIFFERENT ANATOMICAL LOCATIONS BASED ON LOADING AT CONSTANT RATE.
 $T = 1 \times 10^6$ DYNES / CM²

KEY: FIG 1-4

UTL - UPPER THORACIC AORTA

MTL - MIDDLE THORACIC AORTA

LTL - LOWER THORACIC AORTA

UABL - UPPER ABDOMINAL AORTA

LABL - LOWER ABDOMINAL AORTA

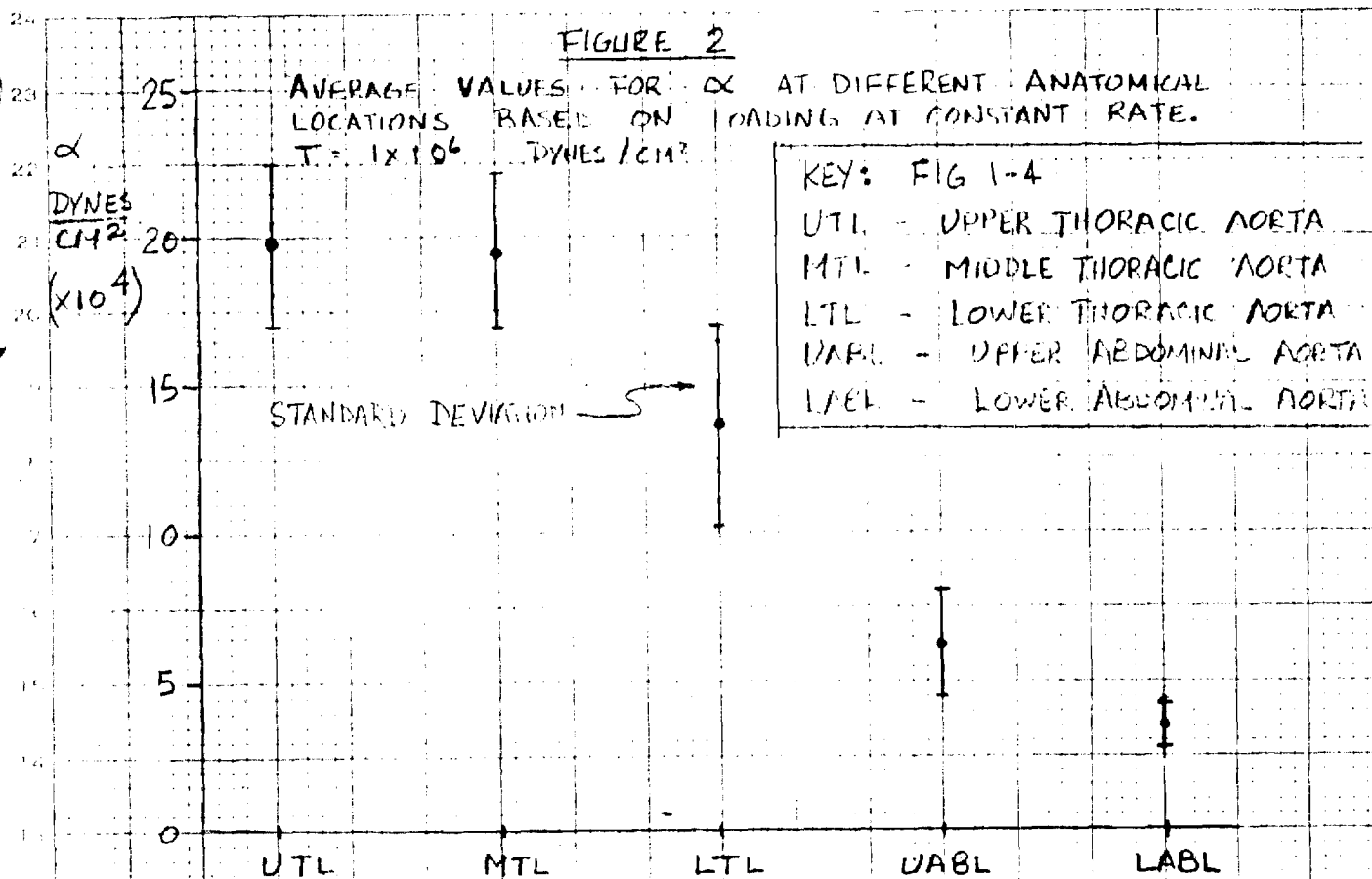


FIGURE 3

AVERAGE VALUES FOR β AT DIFFERENT ANATOMICAL LOCATIONS BASED ON LOADING AT CONSTANT RATE.
 $T = 1 \times 10^6$ DYNES / CM²

β

2.5

2.0

1.5

1.0

0.5

UTL

MTL

LTL

UABL

LABL

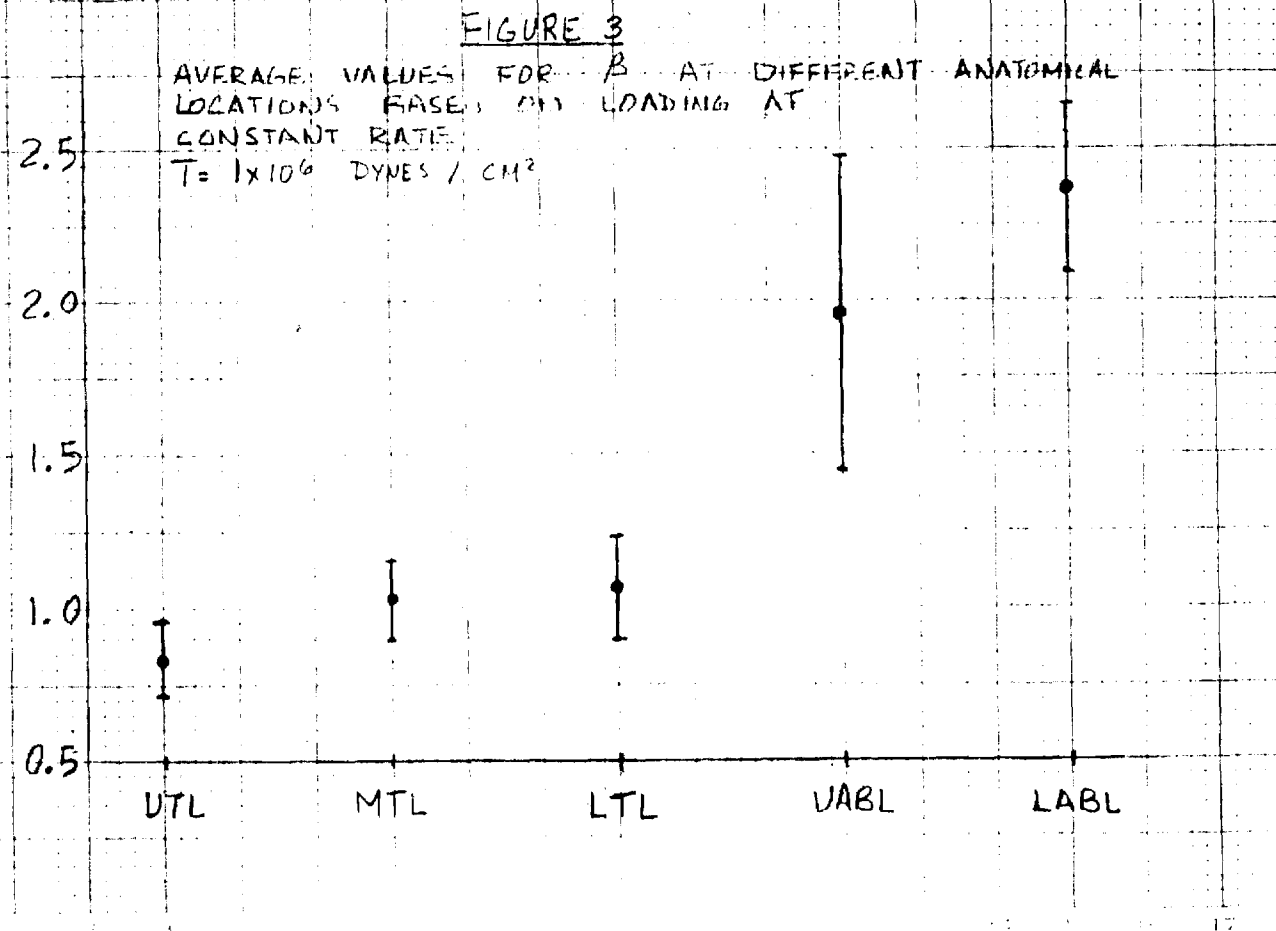


FIGURE 4

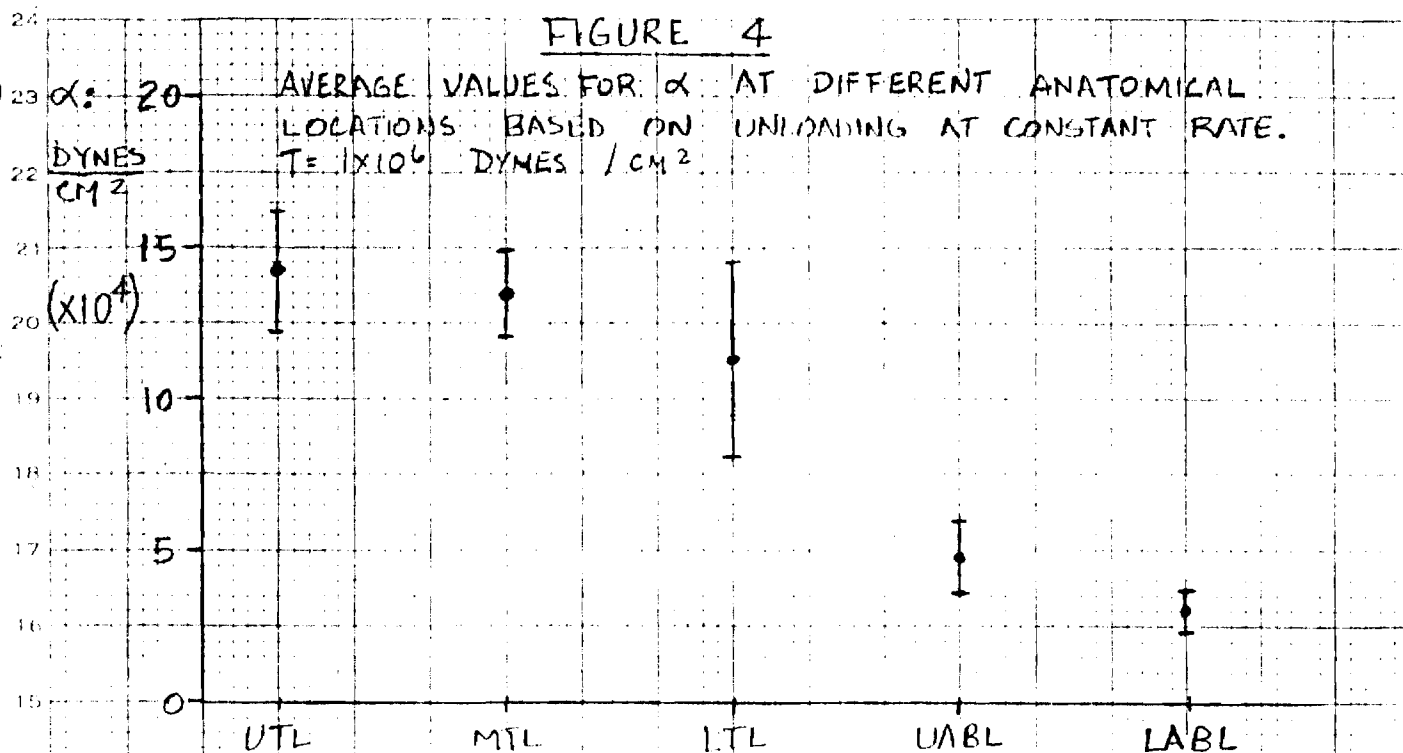


FIGURE 5

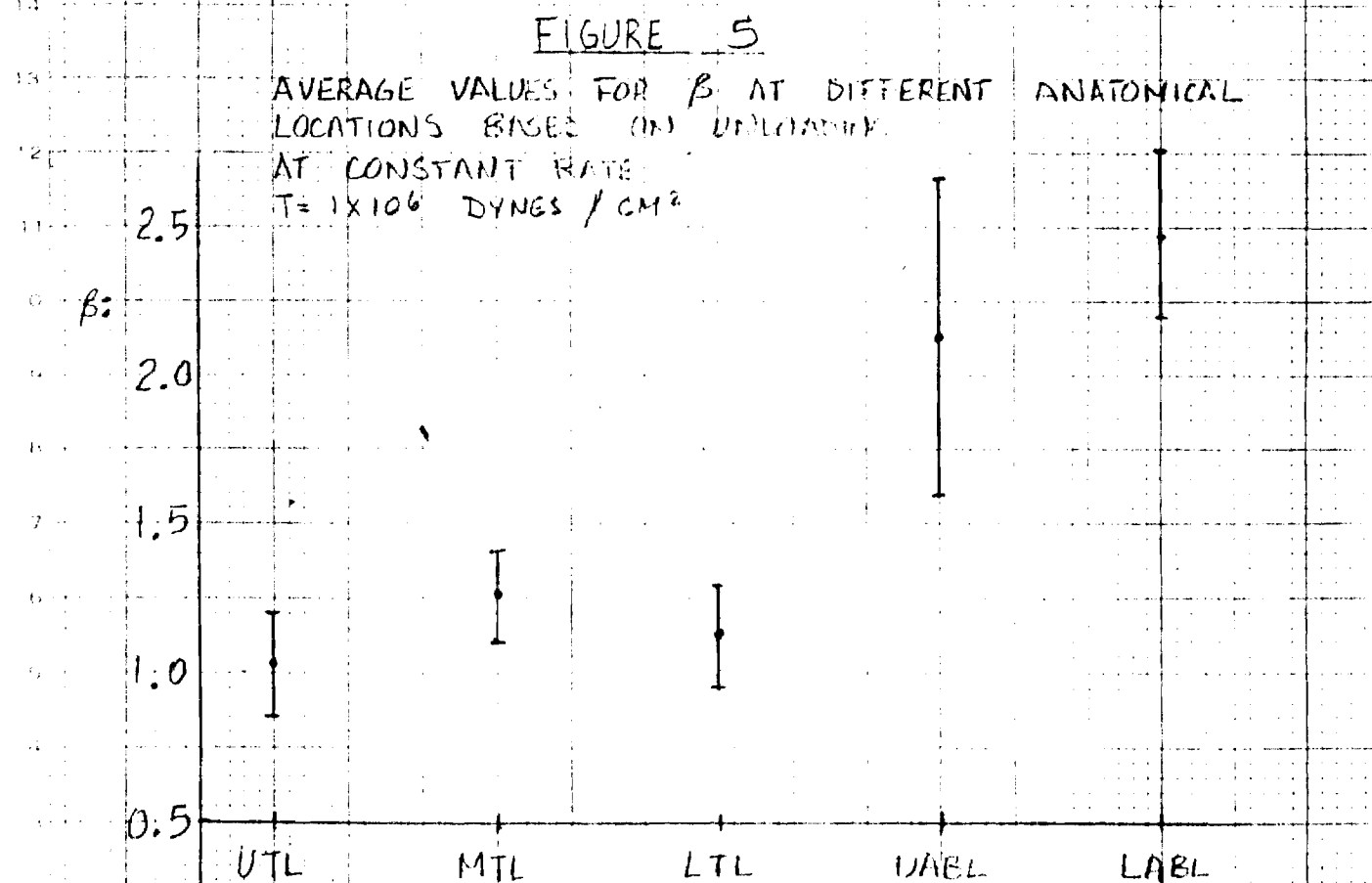


FIGURE 6

RATIO OF ELASTIN TO COLLAGEN + ELASTIN IN DIFFERENT
SITES OF CANINE AORTA. REDRAWN FROM HARKNESS, ET AL.

$\frac{E}{C+E}$
(%)

60

40

20

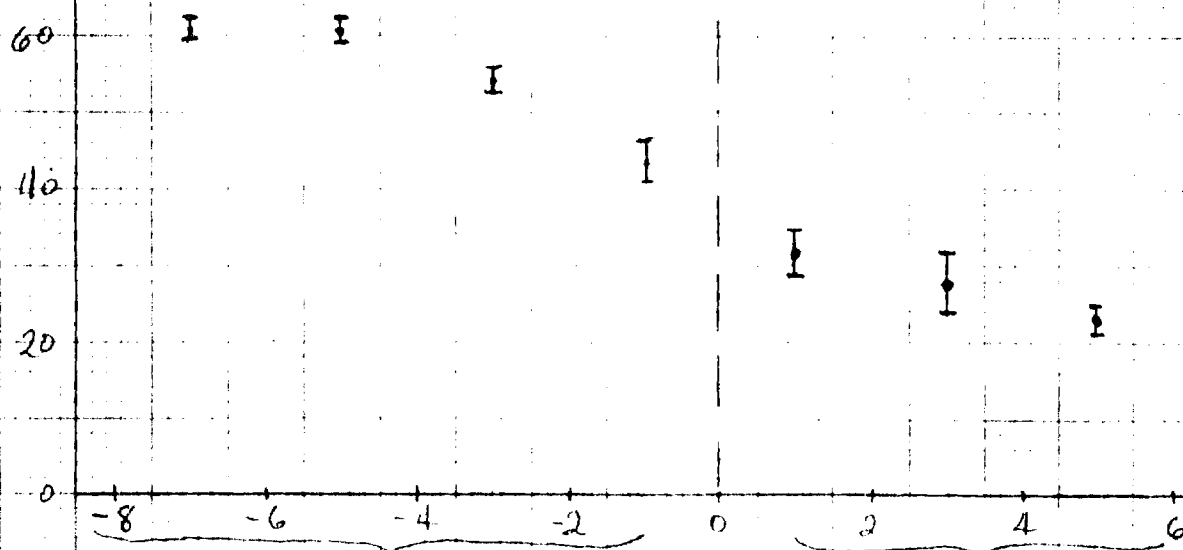
0

-8 -6 -4 -2 0 2 4 6

THORACIC AORTA

ABDOMINAL AORTA

DISTANCE FROM THE DIAPHRAGM (CM)



VITO
Last NameRP
InitialsVITO
Last NameRP
InitialsVITO
Last NameRP
InitialsVITO
Last NameRP
InitialsPlease Check Preference ☒ Traditional Session ☐ Poster Session

INSTRUMENTATION FOR THE MECHANICAL PROPERTIES OF ARTERIES

by R. P. Vito, J. D. Harry and R. D. McCall,
Georgia Institute of Technology*
and R. E. Priest,
Emory University**

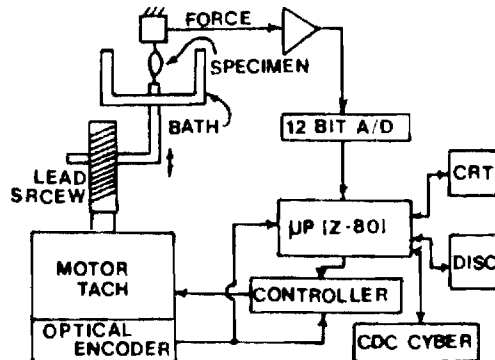
Introduction

Studies of the mechanical properties of arteries may be motivated by the as yet undefined role of arterial mechanics in the genesis and detection of arterial disease (Fry 1973). Non-invasive measures of mechanical properties may also serve as a basis for assessing the state of disease (Fronck 1973).

In-vitro experimental studies are complicated by the nonlinear viscoelastic nature of the specimens and the variations of structure which occur both naturally and as a result of disease. The load-history dependent nature of the response requires that loading and unloading be carefully defined and reproducible. Specimens also exhibit large deformation under the action of small forces. However, most "off-the-shelf" instrumentation is designed for small deformation in response to relatively large forces. Finally, the experimental system must facilitate the handling of the large volumes of data necessary for statistically valid conclusions.

Instrumentation

Microprocessor based instrumentation has been developed for studies of the uni-axial mechanical properties of arteries. The system is shown in block form below.



Position accuracy is $\pm 2.54\mu$ (theoretical) and the maximum rate of loading is 7.5 cm/sec. Step response is 4.0 cm in ~ 1.0 sec.

Experiment

Experimental data consists of measurements of initial specimen length L_0 and cross sectional area A_0 , digitized values for the stretching force F and a count of encoder pulses. The latter serve as a measure of length change ΔL .

Because the device is programmable a wide variety of mechanical tests can be run. As an example, consider the constant strain rate test. In such tests, the specimen length at zero force changes approaching a limit (L_{pc}) after 5/10 load/unload cycles (Fung 1973). This length may serve as the basis for an analysis. Since the deformation is large, the Eulerian stress $T/F/A$, where A

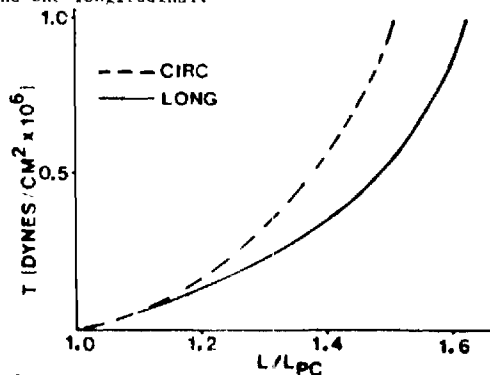
is the area of the deformed cross section, is relevant. The tissue is approximately incompressible, hence

$$A_0 L_0 = A L$$

where L is the deformed length. The Eulerian stress is then $T = FL/A_0 L_0$. In our experiments the peak value of T was controlled. By thus "fixing the end points", results may better reflect the structural variations and differences in anatomical orientation among the specimens. Control was based on ~ 1000 samples/second.

Analysis and Results

Individual load/unload cycles may be analyzed using the theory of large elastic deformation (Vito 1979). The curves below show the differences in the pre-conditioned response (load) of two segments of upper thoracic aorta of dog; one circumferential and one longitudinal.

References

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- Vito, R. P., The role of the pericardium in cardiac mechanics, *J. Biomech.* 587-92 (1979).

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